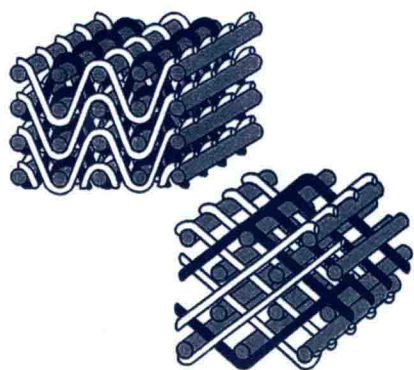


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3-D fibrous assemblies

Properties, applications
and modelling of
three-dimensional textile
structures

Jinlian HU



The Textile Institute

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3-D woven, knitted, braided or stitched fibrous assemblies are textile architectures having fibres oriented so that both the in-plane and transverse tows are interlocked to form an integrated structure that might have a unit cell with comparable dimensions in all three orthogonal directions. This integrated architecture provides improved stiffness and strength in the transverse direction and impedes the separation of in-plane layers in comparison to traditional 2-D fabrics. Recent automated manufacturing techniques have substantially reduced costs and significantly improved the potential for large-scale production of such structures.

I always felt that a comprehensive book on 3-D fibrous assemblies would provide a great support for the industry and for research/educational institutions in understanding the concepts of these new fabric architectures to develop new products for specific applications such as in composites, medical, sports, geotechnical and aerospace fields.

Hence, this book is the culmination of research into 3-D textiles and their applications to composites and other related areas and is based on thorough and detailed compilation of various topics related to 3-D fibrous assemblies. The detailed information provided in this book has been the collective compilation of works of various researchers in the field, mainly from our own research studies, especially on modelling of multiaxial warp-knitted and multilayer woven fabrics.

The book consists of nine chapters covering the topics from introduction of 3-D fibrous assemblies such as 3-D woven, knitted, non-woven and braided fabrics to the advanced modelling of these fabrics for various applications.

Chapter 1 introduces the various 3-D fibrous assemblies such as 3-D woven fabrics, multiaxial warp-knitted structures, 3-D braided, stitched and non-woven fabrics and their general structures. The principle of production of these fabrics with their advantages over 2-D fabrics is also discussed.

Chapter 2 is an overview of the various applications of these fabrics in composites, medical, aerospace and other fields. Specific applications of 3-D

woven, knitted, braided and non-woven fabrics in composite manufacture are discussed in detail.

In **Chapter 3** a detailed discussion of the structures and manufacturing methods of multiaxial warp-knitted fabrics is presented. The advantages of these fabrics over other fabrics are discussed. In addition, detailed information on various mechanical properties such as tearing, shear, compression and flexural behaviour of these fabrics is also presented in this chapter.

Chapter 4 provides in-depth information on structures of various multi-layer woven fabrics and their manufacturing methods. Various routes to manufacture these fabrics are discussed in detail with suitable illustrations. At the end, detailed information is available on their mechanical properties such as tensile, shear and compression with a brief section on applications of these fabrics.

Chapters 5 to 9 are devoted to the modelling of various preforms of multiaxial warp knits and multilayer woven fabrics. In **Chapter 5** an attempt has been made to discuss in detail some of the modelling techniques used to understand the tensile behaviour of multiaxial warp-knitted fabrics. A macroscopic approach dealing with fabric structure under uniaxial tensile deformation is developed for a greater understanding of the geometry of these fabrics. A model for uniaxial tensile deformation is obtained, which is justified by Instron 4466 tensile testing. In addition, a formula for calculating the tensile modulus of the fabric in any direction is presented.

Chapter 6 describes the modelling methods used to analyze the bending behaviour of MWK fabrics. An elaborate description and interpretation on the bending properties of MWK fabrics are presented, which are based on many bending hysteresis curves obtained on KES-FB-2. Further, a predictive bending model to assess the MWK fabrics based on KES-F experiments in different bending directions is described.

In **Chapter 7** a model for the prediction of the formability of a multiaxial warp-knitted (MWK) fabric to a 3-D surface is described. Fibre and yarn movement during fabric forming can cause adverse effects such as wrinkling and thinning, which will lead to a decrease of the mechanical properties of the finished composite. In addition, the high level of waste generated by subsequent trimming operations is unacceptable. Hence there was a need to establish a model to predict the deformation and possible wrinkles of MWK fabrics during the forming process in order to enable waste-free design and defect predictability. For this purpose, a detailed characterization of the forming behaviour of MWK fabrics containing two bias inserting yarns (TBMWK fabric) is discussed in this chapter.

Chapter 8 presents a comprehensive study on the permeability modelling of multilayer woven fabrics. A framework for flow permeability measurement in resin transfer moulding is discussed. The Darcy law is used to model the flow through the reinforcement fibres where permeability is

a measure of the resistance of the fibres to the flow. Two types of woven fabrics, one fabricated by the monofilament method so as to eliminate the effects of other factors such as fibre bundle on permeability, and the other by using multifilament yarns, are used for modelling. Two models are developed to explain the permeability of these two different varieties of multilayer woven fabrics.

Finally, in **Chapter 9** a detailed theoretical analysis for in-plane impregnation in multilayer woven fabrics is reported in order to understand the mechanism of void formation. Unlike the previous approaches, where the void is formed in the plane of one layer of woven fabric, the void formation in the cross-section of multilayer woven fabrics is presented. Based on two simplified unit cells, which were identified from two typical multiple modes of multilayer woven fabrics, a mathematical model is developed to analyze the formation and size of voids. The flow front and void formation processes are also numerically simulated using the control-volume method.

I sincerely feel that the readers will find the book both interesting and informative as it contains the state of the art information on 3-D fibrous assemblies and their application in various fields.

Professor Jinlian Hu
Hong Kong Polytechnic University

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The content of this book is based mainly on the original work produced by my research students at Hong Kong Polytechnic University. A number of people have contributed their original work, especially towards modelling of multiaxial warp-knitted and multilayer woven fabrics.

I am extremely grateful to Dr K. Murugesh Babu for his consistent help and hard work during the editing and preparation of this book. His outstanding reviewing and editing skills combined with sincere efforts have made this book a meaningful piece of work.

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I would like to acknowledge the generous support of the Hong Kong Government for funding support from the Innovation and Technology Commission over the past several years. From these industry-guided projects, we can realize the significance of 3-D fibrous assemblies to the advanced technical textiles field as well as to the research and academic world.

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Introduction to three-dimensional fibrous assemblies

Abstract: Three-dimensional (3-D) textiles are those materials that have a system or systems in all three axes of plane. These materials offer particular properties, such as interlaminar shearing force, mechanical and thermal stability along all three axes of space, that are not achievable with other reinforcements. The development of three-dimensional textiles has taken place rapidly over the past two decades. It can be credited largely to the growth of another technology: composite materials, which combine fibres and a matrix. An understanding of the production methods and structures of these 3-D fibrous assemblies would go a long way in design, process control, process optimization, quality control, clothing manufacture and development of new techniques for specific end uses. This chapter introduces various 3-D woven, knitted, non-woven, braided and stitched fabrics with their brief description and advantages.

Key words: three-dimensional (3-D) textiles, 3-D woven fabrics, 3-D knitted fabrics, 3-D non-woven fabrics, 3-D braided fabrics.

1.1 Introduction: concepts of three-dimensional fibrous assemblies

Textile structures such as in woven, knitted, non-woven and braided fabrics are being widely used in advanced structures in the aerospace, automobile, geotechnical and marine industries. In addition, they are finding wide application as medical implants such as scaffolds, artificial arteries, nerve conduits, heart valves, bones, sutures, etc. This is because they possess outstanding physical, thermal and favourable mechanical properties, particularly light weight, high stiffness and strength, good fatigue resistance, excellent corrosion resistance and dimensional stability. In addition, they act as attractive reinforcing materials in various composite applications with low fabrication cost and easy handling (Tan *et al.*, 1997). With high-end applications such as in aerospace, the orientation of the fibrous reinforcement is becoming more and more important from a load-bearing point of view, as is the need for placing the reinforcement oriented in the third dimension (Alagirusamy *et al.*, 2006).

Textile fabrics, termed preforms in composites and other applications, consist of various reinforcing fabrics such as wovens, knits, braids and